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Title: Multi CCD Vacuum Test Vessel – Vacuum Analysis

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Abstract Summary:
Outgassing rates and Vacuum Pumping Speeds are calculated for the Mulit- CCD Test Vessel and also for the real Camera Vessel.

Applicable Codes:

Introduction

The Multi-CCD test vessel is used to test up to 6 CCDs at one time. The test vessel is a full scale prototype of the real Camera Vessel which will contain 70 CCDs. A desired vacuum pressure of 10e-6 Torr is required in the vessel to prevent water vapor from condensing onto the CCDs during operation. To achieve the required vacuum, a turbo pump and dry rougher pump are used to initial remove most of the gas. Once the ultimate pressure of the turbo pump has been achieved, the turbo pump is turned off and cryo pumps and ion pumps take over to maintain the desired pressure. The turbo pump is isolated from the system using a gate valve. The turbo pump is isolated from the system since in the real Camera Vessel system there is not enough space to carry a turbo pump with the vessel and vibrations are a concern.

Gas loads and required pumping speeds are calculated for the Multi-CCD test vessel.

The ultimate vessel pressure for the real Camera Vessel is calculated using the following constraints. The largest pump flange that fits on the real Camera Vessel in its current configuration is a 6 inch flange. The turbo pump and ion pump used in the calculations is selected as the largest capacity pump that will fit on a 6 inch flange.

Vessel Description

The Multi-CCD test vessel is a 24 inch diameter, 28.375 inch long vacuum vessel. The test vessel is used to test up to 6 CCDs at one time. Kapton cables approximately 2 cm wide by 35 cm long are used to readout the detectors. Two G-10 boards 13 cm tall by 35 cm long are used inside the vacuum as an electronic signal feed thru board. The vessel itself is all stainless steel, however the rear flange cover is constructed of aluminum. The front window is fused silica and is 52 cm in diameter. The window, the window stainless steel mounting flange, rear cover, and vacuum interface board flanges all use o-ring seals. All other instrumentation flanges use copper gaskets.

Multi-CCD Vacuum Vessel Outgassing Rates

Out-Gassing Materials:

Material	Number	Surface area Each	Total surface area	150 hr Outgassing rate	Expected gas load
		cm2	cm2	Torr.L/(s.cm^2)	Torr.L/s
Kapton cables	10	142	1420	7.5e-8	1.06e-4
G-10 Feed thru board	2	925	1850	1.05E-09	1.94e-6
Stainless steel	1	5200	5200	1e-10	5.2e-7
Alum. Cover	1	2917	2917	1.00E-10	2.92e7
Alum. Focl Plate	1	4100	4100	1.00E-10	4.1e-7
Window	1	1962	1962	4.00E-09	7.85e-6
Total					1.17e-4

Outgassing rates from BTEV 150 hr test.

Permeation thru O-rings:

Material	Number	Linear Inch of seal	Total linear inches	Air Permeation rate	Expected gas load
		in	in	Torr.L/(s.inch)	Torr.L/s
Viton End cover flanges And glass window	3	63	189	2.5e-8	4.7e-6
Viton VIB flanges	2	14	28	2.5e-8	7e-7
Total					5.4 e-6

Permeation reference: Vacuumlab.com

TOTAL GAS LOAD = 1.2e-4 Torr.L/sec

Calculate the Required Turbo Pumping Speed:

Desired Ultimate Vacuum Vessel Pressure Less Than:

= 1e-6 Torr

Gas Load:

= 1.2e-4 Torr.L/sec

Required System Pumping Speed:

= Gas Load / Ultimate vessel pressure
= 120 L/sec

Required pumping speed assumes no pumping restriction to the vessel, or the pump is mounted directly to the vessel. The turbo pump is electrically isolated from the vessel using a short ceramic half nipple. Inorder to remove the vacuum pump during telescope operations, a gate valve will also be mounted to the front of the turbo pump. If the Turbo pump is mounted to a 3.75 inch inner diameter tube that is 7 inches long, the conductance of the tube restricts the overall pumping speed.

Conductance of a short 7 inch long, 3.75 inch diameter pipe on the turbo pump:

$$= \frac{\text{sqrt (Pi * 1 * 8.314 * Gas Temp (K)) * (diam)}^2}{\text{Sqrt (18 * 0.028 Kg/mole air)}} * \frac{1}{\text{Length / diam + 4/3 * (1-(diam2/diam1)}^2\text{)}}$$

= 347 M^3/ sec = 347 L/sec conductance

(formula from Cryogenic Systems, R.F. Barron)

With a 180 L/sec turbo pump the overall pumping speed is

= 1 / (1/ 347 L/sec + 1/ 180 L/sec) = 120 L/sec

A minimum Turbo pumping speed of 180 L/sec is required to achieve an Ultimate Vessel Vacuum Pressure of 1e-6 torr

Calculate Cryopumping Speed and Ion Pumping Speeds:

Once the vessel has been pumped down to 1e-6 with the turbo pump, Cryopumping and an Ion pump will be used to maintain the vessel vacuum pressure. Cryopumping will remove the water and the Ion pump will remove the other gases like Nitrogen that don't freeze out on the cold surfaces. The majority of the gas load is water vapor, the nitrogen gas load was determined by Btev experiments as approximately100 times less than the overall gas load. To be conservative, a desired vessel vacuum pressure of 1e-7 Torr is used.

Calculating the required Cryopumping Surface area:

Desired Ultimate Vacuum Vessel Pressure Less Than:

= 1e-7 Torr

Gas Load:

= 1.2e-4 Torr.L/sec

Required System Pumping Speed:

= Gas Load / Ultimate vessel pressure
= 1200 L/sec

The cold surfaces are internal to the vessel volume so there is no additional restriction due to lengths of piping.

Cryo pumping Speed:

= 140,000 L/sec. per square Meter of cold surface area

Required Cold Surface area:

= 1200 L/sec / 140,000 L/sec .M^2
= 9 e-3 square meters
= 90 square cm. of 77K temperature surface

Calculating the required Ion Pump pumping speed:

Desired Ultimate Vacuum Vessel Pressure Less Than:

= 1e-7 Torr

Gas Load:

The gas load of gases other than water vapor is about 1% the total gas load. This number is taken from the BTeV vacuum outgassing tests.

= 1.2e-4 Torr.L/sec * 1%
= 1.2 e-7 Torr.L/sec

Required Ion Pumping Speed:

= Gas Load / Ultimate vessel pressure
= 12 L/sec

Sizing the Pumps for the Real Camera Vessel:

The Real Camera Vessel will have 7 times the number of cables, which are the dominate gas load.

Total Gas load **= 1.2 e-4 * 7**
= 8.4 e-4 Torr.L/sec

Calculating the Vessel Pressure when using the Turbo Pump:

Gas Load:
= 8.4 e-4 Torr.L/sec

Turbo Pumping Speed:
= 200 L/sec

Conductance to the Turbo Pump:
= 347 L/sec

System Pumping Speed:
= 1 / (1/ 347 L/sec + 1/ 200 L/sec) = 126 L/sec

Ultimate Vacuum Vessel Pressure:
= Gas Load / System pumping Speed
= 6.7 e-6 Torr

Calculating the Vessel Pressure when using CryoPumping and the Ion Pump:

To be conservative an ultimate vessel pressure of 1e-7 Torr is used.

Cyropumping:

Desired Ultimate Vacuum Vessel Pressure Less Than:
= 1e-7 Torr

Water vapor Gas Load:
= 8.4 e-4 Torr.L/sec

Required System Pumping Speed:
= Gas Load / Ultimate vessel pressure
= 8400 L/sec

Cryo pumping Speed:
= 140,000 L/sec. per square Meter of cold surface area

Required Cold Surface area:
= 8400 L/sec / 140,000 L/sec .M^2
= 6 e-2 square meters
= 600 square cm. of 77K temperature surface

Calculating the required Ion Pump pumping speed:

Pumping speed:

= 75 L/sec

Gas Load:

The gas load of gases other than water vapor is about 1% the total gas load.

= 8.4e-4 Torr.L/sec * 1%

= 8.4 e-6 Torr.L/sec

Ultimate Pressure:

= Gas Load / Pumping speed

= 1.1 e-7 torr

Comments about the proposed pumps and pumping speeds:

The proposed pump sizes for the real camera vessel are a ATH-200 L/sec Hybrid Dry Turbo Pump and a 75 L/sec Varian Diode ion pump. Space requirements on the camera vessel do not permit huge pumps or huge pump out ports to be mounted to the camera vessel. For the real camera vessel, a safety factor of 10 was applied to the ultimate pressure of the vessel. To achieve the required vacuum in the vessel, any preconditioning of the vessel would be helpful. For example storing the cables in a dry environment, or pre-baking the vessel at a temperature slightly above room temperature could greatly improve the ultimate pressure and also the pump down times.

Required pumping speeds:
Test Vessel
Turbo Pump, 180 L/sec
Ion pump, 12 L/sec
Minimum 77K Cryo pump surface area, 90 cm^2

Achievable ultimate pressures for the real Camera Vessel:
Turbo Pump, 200 L/sec can achieve 6.6e-6 torr
Ion pump, 75 L/sec can achieve 1.2 e-7 torr
Minimum 77K Cryo pump surface area, 600 cm^2